

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**INFLUENCES OF CLIMATE AND FERTILISER APPLICATION
HISTORY ON VARIOUS MEASURES OF SOIL FERTILITY AND
PRODUCTIVITY IN WAIRARAPA HILL COUNTRY**

A thesis presented in partial fulfilment of the requirements for
the degree of Master of Agricultural Science
in Soil Science at Massey University, New Zealand

James Laing Moir

1994

ABSTRACT

During the agricultural downturn of the mid 1980's, it became uneconomic for many Wairarapa farmers to apply fertiliser. Those farmers who could afford to apply maintenance fertiliser, often chose to apply diammonium phosphate (DAP). The increasing popularity and apparent effectiveness of fertilisers such as DAP, which has a nitrogen component, prompted further questions of whether traditional P and S fertiliser application (as single superphosphate), applied to stimulate pasture legume growth and biological nitrogen fixation, was the most cost effective fertiliser strategy. A review of literature revealed that soil fertility and pasture production data for different rainfall regimes in the Wairarapa was scarce. No published data was available on how effective single superphosphate (SSP) applications to Wairarapa hill country farms had been in increasing annual N fixation rates and plant-available soil N, and hence increasing pasture production.

It was concluded that it was necessary to conduct a series of pasture field trials on sites varying in soil type, fertiliser history and climate (annual rainfall) in order to provide data applicable to the Wairarapa region. Sites falling within three rainfall regimes were selected, those being Mauriceville (high rainfall), Gladstone (summer dry) and Whareama (low rainfall) sites. Using total soil phosphorus, sulphur and nitrogen analyses, a total of 14 sites were selected for study, with sites ranging in fertility status within each climate zone. The objective has been to characterise the soil types, soil nutrient status, climate and current pasture production of Wairarapa hill country farms, with a view to completing further studies examining in more detail the complex interactions of soil, climate and pasture.

Soil chemical analyses revealed a wide range of soil fertility status across all sites. Soil total phosphorus (P) contents ranged from 430 $\mu\text{gP/g}$ soil (site 4) to 1470 $\mu\text{gP/g}$ (site 1), while total soil sulphur (S) showed less variation, ranging from 345 $\mu\text{gS/g}$ (site 11) to 860 $\mu\text{gS/g}$ (site 9). Soil total nitrogen (N) contents followed a similar pattern to that seen for total S, and ranged from 4280 $\mu\text{gN/g}$ (site 11) to 7950 $\mu\text{gN/g}$ (site 9).

Fertiliser history had a large influence on the accumulation of P, S and N in these hill country soils, where higher rates of accumulation were associated with greater levels of fertiliser

input. However, P accumulated at a far greater rate than S and N in these soils, which is possibly the result of high S and N leaching losses. Measurements of plant-available nutrient levels followed a similar trend to that seen for soil total elemental analyses, where higher levels of nutrient were correlated with higher fertiliser inputs.

Estimates of the efficiency of past fertiliser applications were made for these sites, using the results of various soil analyses. Traditional P and S fertiliser applications and pasture management on Wairarapa hill country appear to have been particularly inefficient in causing soil N to accumulate. The calculations used to derive these estimates have limitations, but do indicate that either product N and leaching losses are high or N fixation rates are low (or both) in these soils.

July 1993 to March 1994 was an average growing season, and total herbage yields harvested from August 1993 to March 1994 ranged from 4 tDM/ha (site 4) to 15.5 tDM/ha (site 1). Soil fertility status (and hence historical SSP applications) was the main factor influencing total herbage yield, where high yields were recorded at high fertility sites, and the reverse for low fertility sites. Climate (soil moisture levels) also influenced total yield but to a lesser extent than soil fertility status.

Pasture growth at Gladstone and Whareama sites stopped when soil volumetric water content in the top 7.5 cm fell below 0.2. At the wetter Mauriceville sites, soil moisture was not limiting until mid-February 1994. Legume growth was particularly sensitive to soil moisture stress.

By converting pasture production to stock units, gross margin analyses were performed. The most profitable options in all three rainfall regimes were sites which had received frequent fertiliser applications. This suggests that historical fertiliser applications are economically effective, which is an important factor in sustainable agricultural enterprises.

Herbage N and P uptake results supported this finding, and showed that pasture N uptake varied widely between high and low fertility sites. Pasture N uptake ranged from 70 kgN/ha at low fertility site 4, to 250 kgN/ha at high fertility site 1 for the period of early August

1993 to early January 1994. This implies that historical superphosphate applications have been effective in providing large increases in annual amounts of plant-available soil N at high fertility sites when compared to unfertilised sites, despite the fact that soil N accumulation was less than expected.

Acetylene reduction activity (ARA) measured at each harvest showed that annual N fixation levels are limited by extended summer dry periods which stop legume growth. The wetter Mauriceville sites fixed more N on an annual basis than Gladstone and Whareama sites. ARA was linearly related to yield. Variations in the data indicated that species and other short-term soil condition changes have a large effect on the relationship between ARA and N fixation rates.

Although soil N accumulation is slow in these pasture systems, annual pasture N uptake is dramatically increased where fertiliser inputs have been high. The results indicate that rapid cycling of soil/plant N is occurring, and that annual leaching and product losses of N may nearly equal N fixation rates. This was exemplified in a simple budget of the nitrogen cycle, taking account of N losses and gains in a low fertility and high fertility system. There was insufficient information to conclude why soil N is not accumulating in these grazing systems. Further research is required to fully explain this N cycle, including the relative quantities of N inputs and losses from the system.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the following people for their contributions to this thesis.

Firstly, to Dr. M.J. Hedley for his supervision, patience and support over the course of this study. Secondly, to Dr. A.D. Mackay for his supervision and constructive suggestions, and Chris Garland for contributing local knowledge and feedback.

Bob Toes for his assistance with laboratory work, and all staff in the Department of Soil Science for their contributions.

Mr A. Hammond for proof-reading and giving useful comment on this script, and Ms N. Collins for valuable assistance in thesis preparation.

Finally, I wish to acknowledge the following Wairarapa farmers on whose farms sites are located, for their assistance and cooperation over the past eighteen months; Messers D Blackwood, B Christensen, A Day, D Dunlop, N Kilmister, D Kinnell, K O'Riley, D Williams.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	x
LIST OF FIGURES	xv

CHAPTER 1

INTRODUCTION	1
--------------------	---

CHAPTER 2

LITERATURE REVIEW

2.1	SOILS OF THE WAIRARAPA HILL COUNTRY	4
2.1.1	Introduction	4
2.1.2	Yellow-Grey Earths of the Wairarapa	4
2.1.3	Yellow-Brown Earths of the Wairarapa	5
2.1.4	Wairarapa Yellow-Grey Earth to Yellow-Brown Earth Intergrades	6
2.2	FACTORS INFLUENCING THE FERTILITY STATUS OF WAIRARAPA	
	SOILS	9
2.2.1	Sources of Phosphate in Hill Country Rocks of the Wairarapa	9
2.2.2	Evaluation of Fertility Status	11
2.2.3	Nutrient Accumulation and Transformations Under Pastoral	
	Grazing Systems	12
2.2.3.1	Phosphorus	12
2.2.3.2	Sulphur	20
2.2.3.3	Carbon/Organic Matter and Nitrogen	21
2.3	NITROGEN FIXATION IN WAIRARAPA HILL COUNTRY	24
2.4	SUMMARY	25

CHAPTER 3

METHODS AND MATERIALS

3.1	INITIAL SOIL SAMPLING	27
3.2	SITE SELECTION	28
3.3	FERTILISER HISTORY	28
3.4	SITE ESTABLISHMENT	31
3.5	HARVESTING AND DISSECTION OF HERBAGE	31
3.6	THE ACETYLENE REDUCTION TECHNIQUE	32
3.7	SOIL MOISTURE CONTENT	33
3.8	SOIL SAMPLING AND PREPARATION	33
3.9	CLIMATE MEASUREMENTS	33
3.10	SOIL ANALYSES	34
3.10.1	Total Phosphorus	34
3.10.2	Sequential Phosphate Extraction	35
3.10.2.1	NaOH Extraction and Digest	35
3.10.2.2	H ₂ SO ₄ Extraction and Residual P Digest	36
3.10.3	Total Nitrogen	37
3.10.4	Total Sulphur	37
3.10.5	Soil pH	37
3.10.6	Total Carbon	38
3.10.7	Plant-Available Nutrients	38
3.10.7.1	Phosphate	38
3.10.7.2	Resin-Exchangeable Phosphate	38
3.10.7.3	Sulphate	38
3.10.7.4	Exchangeable Cations and C.E.C.	39
3.10.7.5	Mineralisable N	39
3.11	HERBAGE ANALYSES	40
3.11.1	Total Phosphorus and Nitrogen	40
3.11.2	Molybdenum	40

CHAPTER 4

CHEMICAL CHARACTERISATION OF SOIL NUTRIENT STATUS

4.1	INTRODUCTION	41
4.2	ASSESSMENT OF PLANT-AVAILABLE NUTRIENT STATUS OF SOILS .	41
4.2.1	Olsen P	42
4.2.2	Resin-Extractable P	45
4.2.3	Extractable Sulphate	45
4.2.4	Soil pH	48
4.2.5	Soil N Availability Index	48
4.2.6	Exchangeable Cations	48
4.3	CATION EXCHANGE CAPACITY	50
4.4	TOTAL ELEMENT CONTENT OF SOILS	51
4.4.1	Total Soil Carbon (C)	51
4.4.2	Total Soil Phosphorus (P)	51
4.4.3	Total Soil Sulphur (S)	54
4.4.4	Total Soil Nitrogen (N)	54
4.5	PHOSPHATE FRACTIONATION	55
4.6	DISCUSSION	58
4.6.1	The Relationship Between Total Soil P and Total Soil N	58
4.6.2	The Relationship Between Mineralisable Soil N and Total Soil P	61
4.6.3	The Relationship Between Total Soil S and Total Soil P	62
4.6.4	The Relationship Between Total Soil S and Total Soil N	64
4.6.5	The Relationship Between Indices of Available Soil P and Total P or Individual P Fractions	64
4.6.6	The Relationship Between Plant-Available P Extraction Methods	69
4.7	CONCLUSIONS	74

LIST OF TABLES

Table 2.1	Summary of observations of P accumulation and transformation in N.Z. pastoral grazing systems	19
Table 3.1	Site information	30
Table 4.1	N.Z. MAF recommended soil test levels	42
Table 4.2	Soil Olsen P, sulphate S, resin P and mineralisable N values for the 0 - 7.5 cm depth	44
Table 4.3	Soil pH, CEC, total carbon (C) and exchangeable cation values for the 0 - 7.5 cm depth	50
Table 4.4	Total soil phosphorus (P), nitrogen (N) and sulphur (S) content	53
Table 4.5	Sequential fractionation of soil phosphate	57
Table 5.1	Monthly rainfall, maximum/minimum temperature and A.E.T. (October 1993 to January 1994)	77
Table 5.2	Summary of climate, herbage yield and nitrogen fixation levels in the D.I.S.R. national series of N-fixation trials (1979)	118

LIST OF FIGURES

Figure 3.1	Location of Wairarapa trial sites and New Zealand Meteorological Service Climate Stations (A) Mangamutu (B) Castle Point and (C) Taratahi	29
Figure 4.1	Olsen P values for the 0 - 7.5 cm soil depth at all sites	43
Figure 4.2	0.1M Calcium phosphate extractable sulphate values for the 0 - 7.5 cm soil depth at all sites	46
Figure 4.3	Resin-exchangeable phosphate values for the 0 - 7.5 cm depth at all sites	47
Figure 4.4	Mineralisable nitrogen for the 0 - 7.5 cm depth at all sites	49
Figure 4.5	Total soil P, S and N content for the 0 - 7.5 cm depth at all sites	52
Figure 4.6	Fractionation of total soil phosphate components for the 0 - 7.5 cm depth at all sites	56
Figure 4.7a	The relationship between total soil N and total soil P contents for the 0 - 7.5 cm depth at all sites	59
Figure 4.7b	The relationship between total soil S and total soil P contents for the 0 - 7.5 cm depth at all sites	63
Figure 4.7c	The relationship between total soil N and total soil S contents for the 0 - 7.5 cm depth at all sites	65

Figure 4.7d	The relationship between total soil N and total soil S contents, excluding the sulphate S fraction, for the 0 - 7.5 cm depth at all sites	66
Figure 4.8a	The relationship between Olsen P and total soil P (Kjeldahl digest) contents for the 0 - 7.5 cm depth at all sites	67
Figure 4.8b	The relationship between Olsen P and total soil P (sum of sequential P extraction) contents for the 0 - 7.5 cm depth at all sites	68
Figure 4.8c	The relationship between soil resin extractable P and Olsen P contents for the 0 - 7.5 cm depth at all sites	70
Figure 4.8d	The relationship between soil Olsen P and 0.1M NaOH extractable inorganic P (P _i) contents for the 0 - 7.5 cm soil depth at all sites	71
Figure 4.8e	The relationship between resin-extractable (less Olsen-extractable) P and H ₂ SO ₄ extractable P fractions for the 0 - 7.5 cm depth at all sites	72
Figure 4.9	The relationship between mineralisable N and total soil P contents for the 0 - 7.5 cm depth at all sites.	73
Figure 5.1a	Seasonal soil volumetric water contents from 24.8.93 (harvest 1) to 18.3.94 for the 0 - 7.5 cm depth at Mauriceville sites	79
Figure 5.1b	Seasonal soil volumetric water contents from 24.8.93 (harvest 1) to 18.3.94 for the 0 - 7.5 cm depth at Gladstone sites	80
Figure 5.1c	Seasonal soil volumetric water contents from 24.8.93 (harvest 1) to 18.3.94 for the 0 - 7.5 cm depth at Whareama sites	81

Figure 5.2a	Total cumulative dry matter yield from the start of trials (5.8.93) to 18.3.94 at Mauriceville sites	83
Figure 5.2b	Total cumulative dry matter yield from the start of trials (5.8.93) to 30.3.94 at Gladstone sites	84
Figure 5.2c	Total cumulative dry matter yield from the start of trials (5.8.93) to 30.3.94 at Whareama sites	85
Figure 5.3a	Cumulative legume dry matter yield from the start of trials (5.8.93) to 18.3.94 at Mauriceville sites	87
Figure 5.3b	Cumulative legume dry matter yield from the start of trials (5.8.93) to 30.3.94 at Gladstone sites	88
Figure 5.3c	Cumulative legume dry matter yield from the start of trials (5.8.93) to 30.3.94 at Whareama sites	89
Figure 5.4a	The botanical composition of swards at Julian Day 278 (harvest 3) . . .	90
Figure 5.4b	The botanical composition of swards at Julian Day 300 (harvest 4) . . .	91
Figure 5.4c	The botanical composition of swards at Julian Day 343 (harvest 6) . . .	92
Figure 5.5a	The relationship between herbage yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil Olsen P content	94
Figure 5.5b	The relationship between herbage yield from 16.11.93 to 6.1.94 (harvests 6 and 7) and soil Olsen P content	95
Figure 5.5c	The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil sulphate S content	96

Figure 5.5d	The relationship between dry matter yield from 24.8.93 to 5.10.93 (harvests 2 and 3) and soil resin P content	98
Figure 5.5e	The relationship between dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil mineralisable N content	99
Figure 5.6a	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil Olsen P content	100
Figure 5.6b	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil sulphate S content	101
Figure 5.6c	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil resin P content	102
Figure 5.6d	The relationship between legume dry matter yield from day 24.8.93 to 5.10.93 (harvests 2 and 3) and soil mineralisable N content	103
Figure 5.6e	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil Olsen P content	104
Figure 5.6f	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil sulphate S content	105
Figure 5.6g	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil resin P content	106
Figure 5.6h	The relationship between legume dry matter yield from day 16.11.93 to 6.1.94 (harvests 6 and 7) and soil mineralisable N content	107
Figure 5.7	The relationship between herbage P and N concentrations at Julian days (a) 236 (harvest 1); (b) 257 (harvest 2) and (c) 278 (harvest 3)	109

Figure 5.7	The relationship between herbage P and N concentrations at Julian	
(continued)	days (d) 300 (harvest 4); (e) 320 (harvest 5) and (f) 343	
	(harvest 6)	110
Figure 5.8	The relationship between total harvested P and N over the	
	period 5.8.93 to 9.12.93 (Julian Days 217 to 343)	112
Figure 5.9	The relationship between total N harvested and total soil P	
	over the period 5.8.93 to 9.12.93 (Julian Days 217 to 343)	113
Figure 5.10a	Acetylene reduction activity from 24.8.93 to 6.1.94 at	
	Mauriceville sites	115
Figure 5.10b	Acetylene reduction activity from 24.8.93 to 30.3.94 at	
	Gladstone sites	116
Figure 5.10c	Acetylene reduction activity from 24.8.93 to 30.3.94 at	
	Whareama sites	117
Figure 5.11	The relationship between legume dry matter yield and	
	acetylene reduced for the period 24.8.93 to 30.3.94	120
Figure 6.1	A simplified nitrogen cycle in Wairarapa hill country pastures	127

CHAPTER 1: INTRODUCTION

It is generally accepted that in order to maintain improved legume based pastures in New Zealand, the soil phosphorus and sulphur fertility status must be raised and maintained at a higher level than that in native soils. Consequently, high initial applications (capital dressings), followed by smaller annual applications (maintenance) of fertiliser are recommended to raise and maintain appropriate soil fertility conditions for high yielding legume species. In turn, the legume species (principally clovers) are presumed to fix and supply adequate quantities of nitrogen, required for pasture growth (Ball and Tillman, 1994).

However, determining sustainable soil fertility management strategies for pasture can be a difficult task. In the Wairarapa region, factors such as climate, soil type and fertiliser history will have major influence on soil nutrient supply and the relative performance of legumes fixing nitrogen into the system.

There are a number of problems associated with determining appropriate soil fertility strategies for hill-country pastures of the Wairarapa. Climate is variable across the region, ranging from high rainfall areas, to areas which consistently receive extended periods of drought. Such conditions will influence the extent and seasonality of pasture yield, as well as nutrient availability to pasture.

Climate will also have influenced soil formation, nutrient loss and nutrient retention capacity mechanisms in each soil.

Central YBEs, YGES and YBE/YGE intergrades form a mosaic across large areas, making fertiliser recommendations difficult. These soils have formed from a wide variety of parent rocks under different weathering regimes, and so differ in their physical and chemical properties.

Fertiliser history and stocking rate will also influence nutrient requirements. The form and quantity of past fertiliser applications can determine the present soil fertility status, and so influence present fertiliser needs. For example, farms which have historically applied P above

maintenance levels would be expected to have a high soil P status, and have a soil P reserve. In such situations fertiliser P requirements may be low, unless current stocking rates are very high.

Traditional fertiliser policy in the region has relied upon superphosphate, predominantly to supply elevated soil P and S levels for clover growth. The legume in turn fixes N₂, which is subsequently made available to grasses. However, the nutritional adequacy of clovers has recently been questioned (Ball and Tillman, 1994), and current research is focusing on breeding more P-efficient clover cultivars (Dunlop *et al.*, 1988; Caradus *et al.* 1991). It has been suggested that in some situations clovers are inadequate providers of soil nitrogen, therefore maintaining elevated soil P levels for N₂ fixation by clovers is wasteful (Ball and Tillman, 1994). There is a need to investigate whether strategic N fertiliser inputs (plus minimal P and S) are more efficient than traditional superphosphate policies, and if more P-efficient pasture species are required.

Climate may also influence the efficiency of legumes to supply (input) soil nitrogen. For example, areas which are consistently drought prone would be expected to have shortened growing seasons and less N-fixation on an annual basis. Therefore, under drier climate regimes there may be less "effective" N-fixation days, which would limit the supply of mineralisable N to the soil.

Climate may also influence the efficient use and loss of fixed N. In general, annual dry matter production would be expected to be greater in high rainfall areas when compared with drier regimes, and therefore lead to more grazing days. While N fixation may be extended, the longer grazing period could be seen as a longer period for nutrient loss; a problem which may be compounded by higher stocking rates. If this scenario does exist in high rainfall areas, would the reverse be true for drier climate regimes? i.e. less grazing days, lower stocking rates and less nutrient losses?

In order to determine appropriate sustainable soil fertility management strategies, researchers must have a comprehensive understanding of the influence of climate, soil type and fertiliser history, in addition to plant-soil interactions.

This study examines the soils, climate and fertiliser history of the Wairarapa hill-country, with the purpose of evaluating the efficiency of traditional superphosphate applications to pasture.